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TO LOOK INTO THE POSSIBILITY OF USING PENETRATION GRADE ASPHALT BINDER IN STONE MATRIX ASPHALT (SMA) FOR HIGHWAYS AND HEAVY TRAFFIC ROADS IN PAKISTAN

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ABSTRACT

The pavement failures in the form of fatigue cracking/rutting and thermal cracking is a common issue faced throughout the world. It is believed that heavy traffic and the in-service temperature are the main causes of these failures.

The International Pavement Research/Construction Agencies, especially in Europe and America had developed new methodologies and technologies for construction of highways and heavy traffic roads to cope with these problems. These new technologies are the Superior Performing Asphalt Pavements (Superpave) and Stone Matrix Asphalt (SMA). The new technologies have adopted performance grade system for asphalt binder rather than the penetration grade which was used throughout the world for decades in addition to introducing some advance testing and gradation for aggregates.

The properties of performance grade asphalt binder are related to the condition under which it is used and are selected to meet the expected climatic conditions. The performance grade system for asphalt binder is based on the mean high and low temperature which the pavement experiences during its service life.

This switch over to performance grade asphalt binder from penetration grade was a major change in the methodology of production of asphalt binder. As such it was not so easy and took years of research before finally adopting the new system of performance grade asphalt binder.

With continued research and work on the use of Performance Grade Asphalt Binder, many asphalt technologist and pavement specialist still believe that the selection of a PG binder does not guarantee the total pavement performance, other factors e.g properties of aggregates and the mix are equally important for durable pavement structure. It is believed that fatigue cracking is the result of pavement structure / load of traffic and permanent deformation or rutting is directly related to shear strength of the mix, which is controlled by aggregate properties. Pavement low temperature cracking is the only distress directly related to binder properties. **This indicates that selection of proper aggregates with appropriate properties of binder is of prime importance in mix design and future performance of the pavement.**

Due to heavy load of traffic, Pakistan is also a victim of road failures in the form of fatigue cracking and rutting and to some extent thermal cracking. It is need of the time to focus on to new technology of Superpave or Stone Matrix Asphalt (SMA). Superpave provides a cost effective alternative for both conventional and SMA pavements. However many case studies in Europe and America have revealed that the SMA mixes have performed equally good or better than Superpave mixes. According to some agencies SMA is providing a better alternative than Superpave for worst case loading. The high percentage of coarse aggregate resulting in stone-on-stone contact in SMA Mix with high percentage of asphalt binder seems to be more durable than the Superpave mixtures as the aggregate is the main load bearing component.

This paper emphasizes on the need to investigate possibilities of using locally and commercially available aggregates and penetration grade asphalt binders with SMA gradation to produce a mix as per the criteria outlined in SMA Mix design method AASHTO MP 8 and AASHTO PP 41 as it is not possible to introduce performance grade system for asphalt binders in Pakistan at this very stage.

OBJECTIVES

The objectives of the study to be undertaken are threefold:

1. To evaluate whether the aggregates from Taxila, Sargodah and from some others sources in Pakistan can be used to design rut resistant stone matrix asphalt mixture by using locally and commercially available penetration grade asphalt binders.
2. To analyze and compare the properties of SMA Mix by using different NMAS with penetration grade asphalt binders generally used in Pakistan.
3. To make trial sections on different ongoing projects or on sections of different highways to study the behavior of SMA mix with penetration grade asphalt binder under heavy traffic if the laboratory experiments give positive results.

INTRODUCTION

The roads failure in the form of fatigue cracking and rutting and to some extent thermal cracking are increasing day by day in Pakistan. It is believed that heavy traffic and the in-service temperature are the main causes of these failures. Thermal cracking is primarily controlled by the properties of the binder used in the mix and fatigue cracking/rutting is affected by aggregate grading and properties of the mix.

Marshal Method of mix design is followed for all asphalt mixes in Pakistan. The Marshall Method was successfully used for decades but failures in the form of fatigue cracking/rutting have become a serious problem due to increase in load of traffic.

Germany, in 1961, had developed an asphalt mix known as Stone Matrix Asphalt (SMA) to wrestle with the problems of fatigue cracking and rutting. It provided a good rutting and skid resistance and it is being used in Europe for almost 40 years. Stone Matrix Asphalt (SMA) is also being used in America since 1991 and now it is considered a more durable paving option than Superpave mixes. Several case studies have also reported that SMA mixtures have performed equally good or better than Superpave Mixes.

Stone Matrix Asphalt (SMA) consists of coarse aggregate, fine aggregate, mineral filler and asphalt content with or without modifier. The main features of SMA are as follows:

- The coarse aggregate in SMA is 70% or more, providing a stone to stone contact.
- It has a gap gradation rather than dense gradation as present in conventional mixes.
- Performance Grade Asphalt is used as compared to Penetration Grade.
- The asphalt content is also on higher side as compared to other asphalt mixes.
- Asphalt Binder can be modified or unmodified and a stabilizing agent in the form of cellulose fiber is added to stiffen the asphalt and to avoid fat spots on pavement surface.
- The high asphalt content provides a highly durable mixture which is compacted easily and is resistant to fatigue and reflective cracking.
- The thickness of SMA layer is comparatively less than conventional mixes making it cost effective.

The distinguishing features of Stone Matrix Asphalt (SMA) are the coarse aggregate properties/gradation and the performance grade system for asphalt binders. The properties of aggregates as outlined in SMA Mix design method "AASHTO MP 8" are compatible with the properties of locally available aggregates in Pakistan, but the fact that production of performance grade asphalt will take years for start up, cannot be ignored. Under these circumstances, to pace with modern technology it will be wise enough to conduct a study to use penetration grade asphalt binder in SMA Method of Mix Design and study the properties of the mix as per the criteria outlined in AASHTO PP 41 (Standard Practice for Designing Stone Matrix Asphalt (SMA).

A BRIEF REVIEW ON INTERNATIONAL STUDIES FOR STONE MATRIX ASPHALT

As mentioned earlier, Stone Matrix Asphalt (SMA) was developed in Germany in 1960's. Inspired by the success of SMA in Europe, an AASHTO led European Asphalt Study Tour introduced SMA in America in 1990. With its excellent performance, the use of Stone Matrix Asphalt (SMA) in the United States has significantly increased.

The technical basis for SMA is a stone skeleton with stone-on-stone contact unlike the traditional dense graded asphalt mixes where aggregate tends to float in the mix with little or no contact with larger particles. The stone-on-stone contact between high quality aggregates resists shear forces created by the applied loads.

The properties of aggregate are of prime importance and play a vital role in producing SMA Mix that is more durable than the traditional mixes. Studies undertaken to establish the properties of aggregates are shape, texture, angularity and resistance to degradation.

The rut resistant nature of SMA is dependent upon the internal friction and cohesion. Internal friction in-turn depends upon particle shape, surface texture, gradation of aggregate, density of the mix and quantity of asphalt binder used. Cohesion is the binding force and is basic property of asphalt mixes. Cohesion increases with increasing asphalt binder up to a maximum point and then decreases.

Generally 19mm and 12.5mm nominal aggregate sizes are used in SMA mixes. Typical SMA mixes retain 70% of the coarse aggregate on or above 2.36mm sieve with some fine aggregate ie passing from 2.36mm sieve. Passing on sieve #200 is generally on higher side i.e. 8 to 10 % and cellulose fiber is added to prevent drain-down in the mixture due to high asphalt content which can result in fat spots on pavement surface.

Specified Properties of SMA Materials (AASHTO MP 8-03)

COARSE AGGREGATES	Test Method	Specified Values
Los Angeles Abrasion	(AASHTO T 96)	30 % maximum
Flat and Elongated Particles	(ASTMD4791)	20%(3:1)&5%(5:1)
Water absorption	(AASHTO T 85)	2.0 % maximum
Soundness loss	(AASHTO T 104)	15%
Crushed Content (Coarse Aggregate Angularity	(ASTMT5821)	100/90%
Deleterious Materials	(AASHTO T 112)	0.2 %
FINE AGGREGATES		
Soundness Loss	(AASHTO T 104)	15%
Fine Aggregate Angularity (Uncompacted Void)	(AASHTO T 304)	40 to 45 % minimum
Sand Equivalent	(AASHTO T 176)	40 to 50 % minimum
Liquid Limit	(AASHTO T 89)	25%
Plasticity Index	(AASHTO T 90)	NP
ASPHALT BINDER	(AASHTO T 320)	PG Grade (6 % min.)
CELLULOSE FIBER		0.4 % maximum

Properties of SMA Mix (AASHTO MP 8-03)

PROPERTIES	SMA MIX
Grading	Gap Graded
Bitumen used	6 % minimum
Air Voids	3 to 5 %
VMA	17 % minimum
TSR*1 (Moisture Susceptibility Test)	0.70 %
Drain-down	0.3 %
Stability	1 400 Ibs minimum (635kg) (Ref: FHWA)
Laboratory Compaction Method	50 Blows by Marshall Hammer*2 or 100 Gyrations*3
VGA in Mix %*4	<VCADRC.5
Cellulose Fiber %	0.4 % maximum

*1 Tensile Strength Ratio (AASHTO T 283)

*2 Reference from NCAT Report No. 05.xx

*3 100 Gyration by Super Gyratory Compactor

*4 Voids in Coarse Aggregate of Mix

*5 Voids in Coarse Aggregate of Coarse Aggregate only, in dry-rodded condition

Additional Tests for SMA Mix

Determination of aggregate degradation due to compaction by Marshall and Gyratory method.
Rut Testing by Asphalt Pavement Analyzer

Asphalt Binder (Performance Grade)

The asphalt binder used in SMA is the performance grade asphalt binder, which is the most advanced binder grading system resulted from the research of Strategic Highway Research Program (SHRP) in USA. The properties of Performance Grade Binder are based on the climatic conditions in which it is used. It is classified by two numbers e.g. "58-22", "64-28", etc. The first of these numbers is the indication of binder high temperature performance and the second relates to its low temperature performance. The high temperature is based on 7 days average high temperature of the area and low temperature is based on 1 day's low temperature of the surrounding area. PG asphalt binders are specified in 6°C increments. The physical properties of the binder are constant for all PG grades, the difference lies in the temperature at which all requirements must be met.

PG binder testing is conducted in accordance with AASSTO MP1, which includes tests performed on original, short-term aged and long-term aged asphalt binder. Short-term aging is determined by AASHTO T240 which actually reflects the loss of volatiles and oxidation during construction. The oxidation that occurs during the service life of the pavement is known as long-term aging and is determined with the pressure aging vessel test as per AASHTO PPL

Asphalt Binder (Penetration and Viscosity Grade)

The two standard specifications classify asphalt binder based on consistency measured at standard temperature.

ASTM D 946 and AASHTO M 20 are primarily controlled by penetration and ASTM D 3381 and AASHTO M 226 by viscosity tests. In addition flash point, solubility, softening point and ductility are also included in the specifications.

The Marshall Method of Mix Design as per Asphalt Institute Series MS-2 recommends the use of Penetration and Viscosity Grade Asphalt Binder. The classification as the name implies is based on penetration at 25°C and viscosity at 60°C. The penetration and viscosity grade system was successfully used throughout the world for decades. Even the "Strategic Highway Research Program" (SHRP) of USA had adopted the Asphalt Institute mixing and compaction guidelines based on temperature-viscosity relationship of the binder, where:

Range of Mixing = 150 to 190 centistokes

Range of Compaction = 250 to 310 centistokes

ADVANTAGES OF STONE MATRIX ASPHALT (SMA)

As mentioned earlier that the properties of aggregates plays an important role in the performance of SMA Mix. The stone-on-stone contact and high percentage of coarse aggregates, with fines and asphalt binder also on higher side, consideration of coarse and fine aggregate angularity, void in mix comparable with voids in coarse aggregates, introduction of new tests like Drain-down of asphalt, the concept of locking point and determination of rut depth by Asphalt Pavement analyzer etc. have made the SMA mix far more superior and durable than conventional Marshall mix.

Particle Size distribution (Gradation)

The particle size distribution or gradation of an aggregate is one of the most important aggregate characteristics in determining how it will perform as a pavement material. In HMA, gradation helps to determine almost every important property including stiffness, stability, permeability, workability, fatigue resistance, frictional resistance and resistance to moisture damage. (Roberts etal 1996)

SMA is gap graded asphalt mixture with high percentage of coarse aggregates and very small quantity of material is retained on sand size sieves ie between 2.36mm and 0.075mm. . The gap gradation produces a coarse aggregate skeleton having a stone-on-stone contact with each other and this typical structure in SMA Mix plays a key role in establishing the properties of a rut resistant mix.

Without a coarse aggregate skeleton to carry load, the high asphalt binder of SMA Mix could potentially make it susceptible to permanent deformation. So selection of appropriate gradation that guarantees an aggregate skeleton with stone-on-stone contact is of prime importance in designing a SMA Mix.

Coarse Aggregate Angularity

The coarse aggregate angularity is defines as the percentage of aggregates larger than 4.75mm, with one or more fractured faces. This property ensures a high degree of aggregate internal friction and rutting resistance.

Fine Aggregate Angularity

The percent air voids present in a loosely compacted aggregate smaller than 2.36mm is known as the fine aggregate angularity and is mainly dependent on fractured particles of fine aggregate. So higher void content means more fracture faces. This property is also affected by the particle shape, surface texture and gradation. It also ensures high degree of internal friction and rutting resistance in fine aggregate.

By specifying coarse and fine aggregate angularity, the SMA Mix seeks to achieve high degree of internal friction and thus higher shear strength and rutting resistance.

Voids in Coarse Aggregates

The voids in coarse aggregate in dry rodded condition (VCA_{DRC}) are calculated and compared with voids in coarse aggregate of the mix (VCA_{Mjx}). Studies carried out in this regard had shown that coarse aggregate in dry rodded condition in the absence of fine aggregates represent a stone skeleton as there is nothing to hold the aggregates apart. So lesser percentage of VGA in mix (VCA_{Mix}) as compared to VGA in dry rodded condition (VCA_{DRC}) will suggest that coarse aggregate particles are still in contact with one another and had not been pushed apart by fine aggregates. The procedure is adopted in AASHTO PP 41. This stone-on-stone contact is only possible in a gap graded structure and is seldom observed in dense graded material where the coarse aggregate seems to be floating with in the fine material with no contact with each other.

Locking Point

The locking point concept is a relatively new idea for establishing compacting efforts that was originated to reduce breakdown of aggregates due to over compaction. The concept is to limit the efforts of both the Gyratory and Marshall Compaction to a point where the aggregates locks them together and further efforts will only breakdown the aggregates with very little increase in the density of the material.

Drain-down Properties of Bitumen

Drain-down test measures the potential for asphalt binder to drain from coarse aggregate structure while the mix is held at elevated temperature comparable to those encountered during production, storage and placement of mixture.

The test is carried out as per AASHTO T 304 and ASTM D 6390. The maximum allowable Drain-down for SMA Mixes is 0.3%.

Asphalt Pavement Analyzer (APA)

The Asphalt Pavement Analyzer is an automated new generation of Georgia Loaded Wheel Tester (GLWT) used to test the rutting potential on samples prepared on optimum binder content.

COMPARISON OF MARSHALL (CONVENTIONAL) AND SMA MIX:

The main factor that makes SMA Mix superior to Marshall Mix is the selection of aggregate gradation. This is the initial step in designing SMA Mix and proves to be final in establishing the properties of a durable SMA Mix.

The gradation and properties of the materials and the mix are given below:

Marshall and SMA Mix Gradations

Sieve Sizes	Marshall Gradation (ASTM D3515)	SMA Gradation (AASHTO MP8)	Marshall Gradation (ASTM D3515)	SMA Gradation (AASHTO MP8)
	NMAS 19mm		NMAS 12.5mm	
	Passing %		Passing %	
25 mm	100	100		
19 mm	90 — 100	90 — 100	100	100
12.5 mm		50 — 88	90 — 100	90 — 100
9.5 mm	56 — 80	25 — 60		50 — 80
4.75 mm	35 — 65	20 — 28	44 — 74	20 — 35
2.36 mm	23 — 49	16 — 24	28 — 58	16 — 24
0.300 mm	5 — 19		5 — 21	
0.075 mm	2 — 8	8 — 11	2 — 10	8 — 11

Figures 1 to 4 represent the graphical form of above mentioned gradation specifications.

Material Properties used in Marshall Mix and SMA Mix

PROPERTIES	MARSHALL MIX	SMA MIX (AASHTO MP 8)
COARSE AGGREGATES		
Los Angeles Abrasion	40 % max.	30 % max.
Flat and Elongated		20% (3:1) & 5% (5:1)

Particles		max.
Water absorption	2.0 % max.	2.0 % max.
Soundness loss	12%	15%
Crushed Content %	100/NA	100/90
FINE AGGREGATES		
Soundness Loss	12% max.	15 % max.
Sand Equivalent Value	45 % min.	45 % min.
Uncompacted Void Content	MA	45 % min.
Water absorption	2.0 % max.	
Liquid Limit	25%	25%
Plasticity Index %	NP	NP
ASPHALT BINDER	Penetration/Viscosity Grade	Performance Grade
CELLULOSE FIBER	NA	0.4% max.

Mix properties in Marshall and SMA Methods.

PROPERTIES	MARSHALL MIX	SMA MIX (AASHTO MP 8)
Grading	Dense Graded	Gap Graded
Bitumen used	3 to 5 %	6 % min.
Air Voids	Varies for Base & Wearing	3 to 5 %
VMA	As per table in MS 2	1 7 % min.
TSR*1	NA	0.7 % min.
Drain-down	NA	0.3 % max.
Stability	1000 to 1200 kg min.	635Kgmin (Ref:FHWA)
Loss of Stability	20 to 25 %	20%
Flow, 0.25mm (0.01 in)	8 to 16	8 to 16 (Not a Routine Test)
VGA in Mix %*2	NA	< VCA_{DRC}*3

Laboratory Compaction Method	75 blows by Marshall Hammer	50 blows by Marshall Hammer*[4] or 100 Gyrations*[5]

*[1] Tensile Strength Ratio (AASHTO T 283)

*[2] Voids in Coarse Aggregate in Mix

*[3] Voids in Coarse Aggregate of Coarse Aggregate only in dry-rodded condition

*[4] Reference: NCAT Report No. O5.xx

*[5]100 Gyrations by Super Gyratory Compactor

Irrespective of the type of bitumen, the properties specified for SMA Mix are mainly dependent on the properties of the aggregate used and the selected gradation. The gap graded aggregates used in SMA Mix along with asphalt binder of appropriate properties are the controlling factor in achieving the properties like low air voids, high VMA and VCA_{Mjx} less than VCA_{DRC} which ultimately results in a rut resistant asphalt mixture.

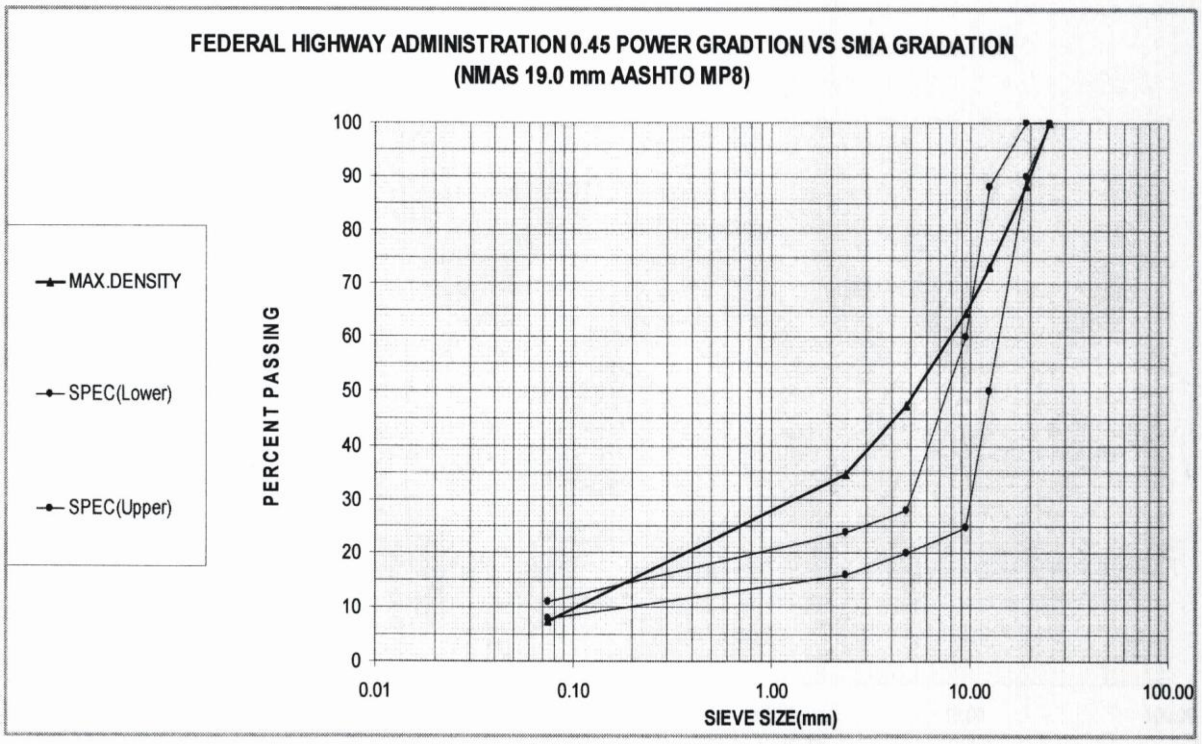
FEDERAL HIGHWAY ADMINISTRATION 0.45 POWER GRADTION VS SMA GRADATION
(NMAS 19.0 mm AASHTO MP8)
MAX.DENSITY
SPEC(Lower)
SPEC(Upper)
PERCENT PASSING
100
90
80
70
60
50
40
30
20
10
0
0.01
0.10
1.00
10.00
100.00
SIEVE SIZE(mm)

Fig 1

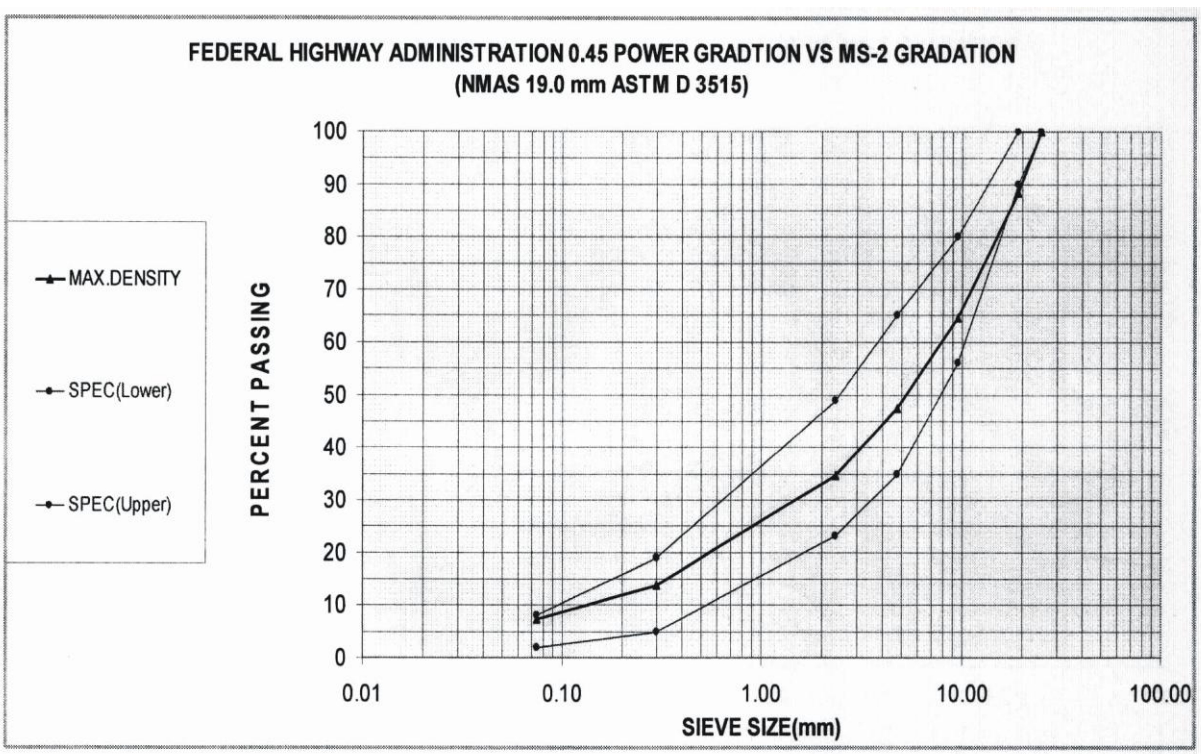
FEDERAL HIGHWAY ADMINISTRATION 0.45 POWER GRADTION VS MS-2 GRADATION
(NMAS 19.0 mm ASTM D 3515)
MAX.DENSITY
SPEC(Lower)
SPEC(Upper)
PERCENT PASSING
100
90
80
70
60
50
40
30
20
10
0
0.01
0.10
1.00
10.00
100.00
SIEVE SIZE(mm)

Fig 2

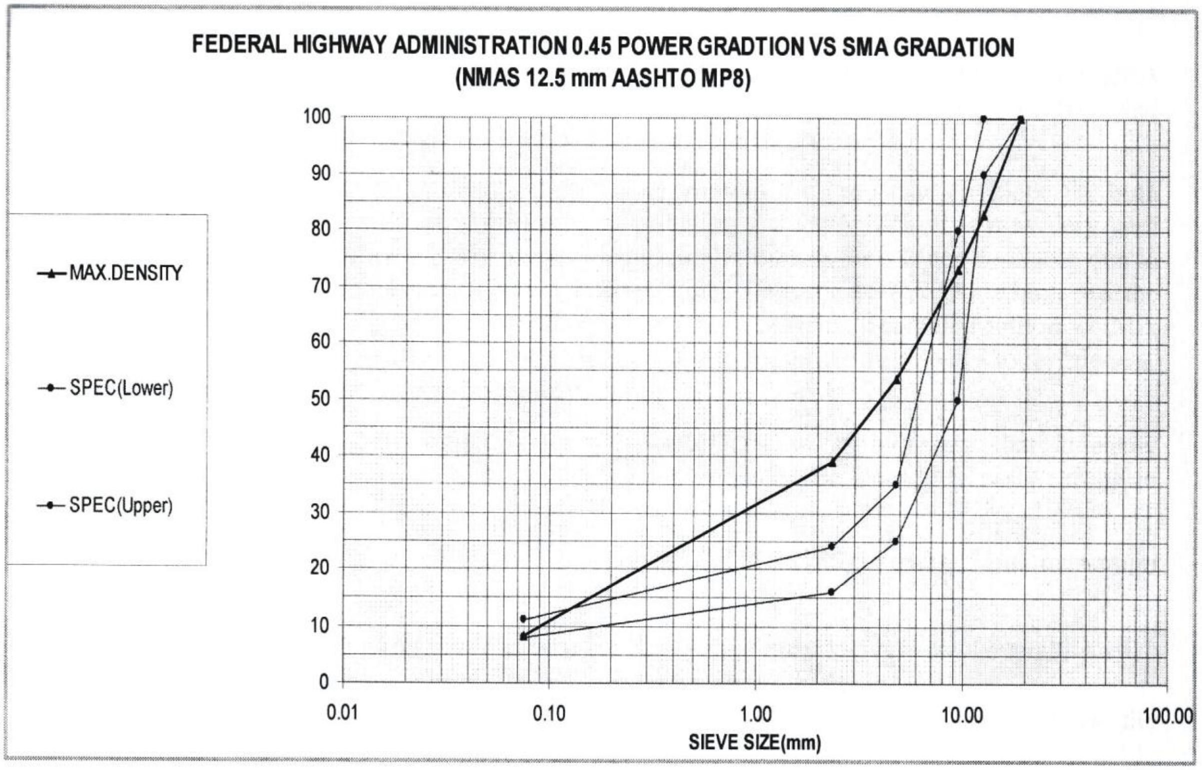
FEDERAL HIGHWAY ADMINISTRATION 0.45 POWER GRADTION VS SMA GRADATION
(NMAS 12.5 mm AASHTO MP8)
MAX.DENSITY
SPEC(Lower)
SPEC(Upper)
100
90
80
70
60
50
40
30
20
10
0
0.01
0.10
1.00
10.00
100.00
SIEVE SIZE(mm)

Fig 3

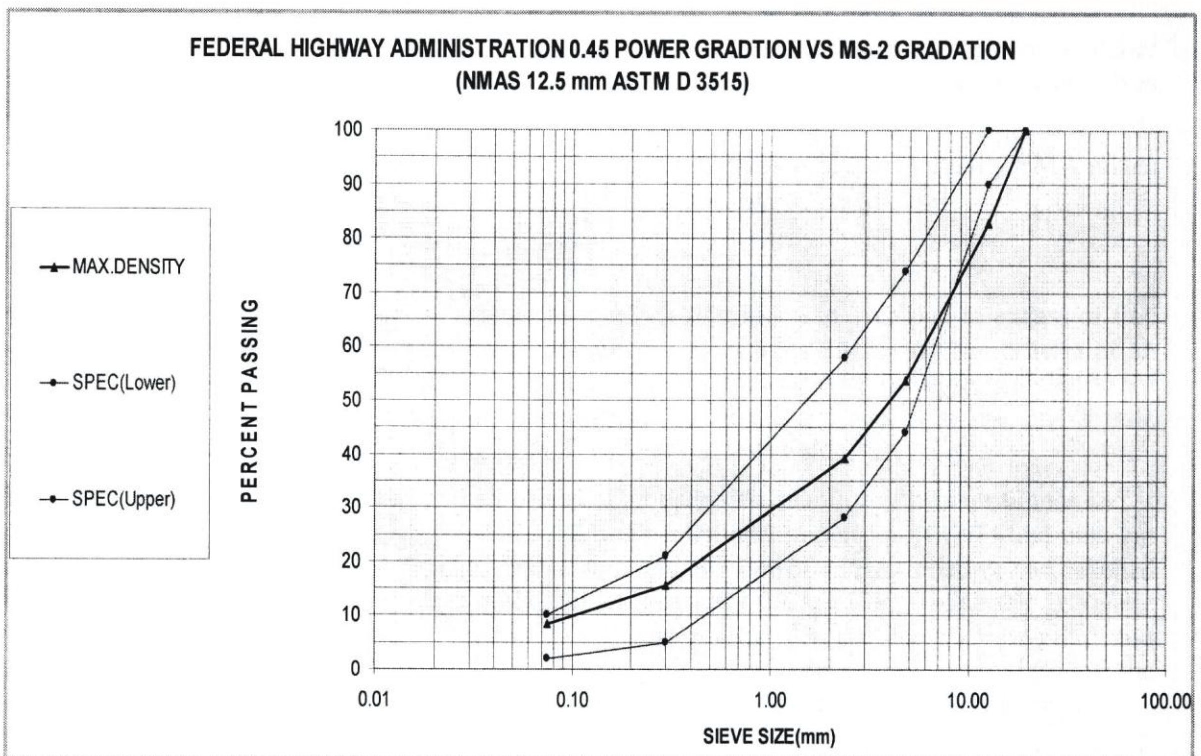
FEDERAL HIGHWAY ADMINISTRATION 0.45 POWER GRADTION VS MS-2 GRADATION
(NMAS 12.5 mm ASTM D 3515)
MAX.DENSITY
SPEC(Lower)
SPEC(Upper)
PERCENT PASSING
100
90
80
70
60
50
40
30
20
10
0
0.01
0.10
1.00
10.00
100.00
SIEVE SIZE(mm)

Fig 4

Particle Size Distribution (Gradation)

The gradation, as mentioned earlier is one of the main factors for producing a rut resistant SMA Mix. The difference in gradation specified in MS-2 and used for Marshall Design Method and that specified for SMA Mix in AASHTO MP8 is obvious from figure 1 to 4.

For Marshall Design the maximum density line passes through the gradation envelope for both 19mm and 12.5mm NMAS, while it is far away in gradation for SMA Mix. It is now very well documented that gradation which closely passes the maximum density line is not desirable due to the fact that such blends produce very low voids in mineral aggregate (VMA) which are the spaces occupied by asphalt binder and air voids. The low VMA in Marshall Method of Mix Design are catered for by lowering the asphalt binder which sometimes leads to brittleness, accelerated oxidation and increased permeability.

The blend approaching the maximum density line produces an asphalt mix that is easily compactable and hence has a tendency to get compacted under traffic leading to early rutting in some cases.

The gradation envelope specified for SMA Mix in AASHTO MP8 is away from maximum density line and has the following advantages:

- As the medium size aggregates are less, the stone-on-stone contact is easily established.
- Higher Voids in Mineral Aggregate are achieved without difficulty.
- Higher bitumen content properly coats the aggregate which in turn improve the durability of the mix.
- Higher VMA solve the problem of flushing of excess asphalt binder.
- The high mineral filler along with cellulose fiber acts as stabilizer to prevent the asphalt binder from draining out of the mixture.
- Flexibility of the asphalt mix is also enhanced by high asphalt content and open graded aggregate structure.

The aggregate skeleton formed with gap grading in SMA Mix, not only allows for a higher asphalt content which gives a thicker asphalt film around the aggregate particles but also solves the problem of flushing of excess asphalt binder due to high VMA.

New research is affirming the value of gap graded Superpave mixes that are actually SMA mixes incorporating Superpave Technology.

Asphalt Binder (%)

Generally the asphalt binder used for asphalt mix in Pakistan is 3% to 5%. Due to excess of fine aggregates and dense gradation this amount of asphalt binder does not satisfy the criteria of an appropriate film thickness around the aggregates. The thin film around the aggregates does not give proper bonding which results in the problems of raveling and potholes at site, and a little excess asphalt binder gives rise to rutting as the VMA are on lower side.

It is believed that durability of the asphalt mix depend upon the quantity of asphalt binder and is generally improved by high asphalt binder, well compacted and impervious mix. Maximum rut resistance is not possible in an aggregate mass until the amount of asphalt coating had reached some critical value. The higher asphalt binder which results in thicker film around the aggregate particles is more resistant to age hardening and thus reduce the problems of raveling and pavement brittleness. Higher amount of asphalt binder also reduces the pore sizes of the interconnected voids making difficult for air and water to intrude the mix and cause damage.

Sufficient asphalt binder is also necessary to provide proper bonding to the aggregates to overcome the abrasive forces of traffic. It is also acknowledged that proper quantity of asphalt binder is extremely important for fatigue resistance of pavement. As a rule, higher the asphalt content the greater is the fatigue resistant.

Stability

Stability is not included in the specification for SMA Mix in AASHTO MP 8 and PP41. The Federal Highway Administration (FHWA) has suggested a value of 635 Kg for stability as compared to 816 Kg min. in Marshall Method of Mix Design which in-turn is increased to 1000 Kg. in our National Specifications.

It is usually observed that due to dense gradation specified in Marshall Mix Design, the stability value obtained is much higher. As per Asphalt Institute Manual Series MS-2, extremely higher stability often is obtained at the expense of durability. The asphalt mix with higher stability value attributes to a rigid pavement rather than a flexible one which becomes brittle and cracks under load in a short span of time. So it is required that aggregate gradation and asphalt content in the final mix design must strike favorable balance between stability and durability requirement. This balance is the prime factor in SMA Mix Design Method, as with the gap graded aggregate and higher % of bitumen (with addition of Cellulose fiber) the stability of the mix rarely exceed 1000kg.

Voids in Mineral Aggregates (VMA)

One of the most important factors that contribute to the durability of asphalt mix is the presence of adequate amount of Voids in Mineral Aggregates (VMA). In Marshall Method of Mix Design, achieving the minimum amount of VMA is always a problem as the specified gradation results in very dense packing of aggregates leaving very little room for VMA. Adjusting for VMA is sometimes a compromise on quality of the mix and durability of the pavement.

As per AASHTO MP 8 the minimum specified VMA for SMA Mix is 17 %. The work carried out by international agencies and international contractors on different projects in Europe and America have proved that this minimum criterion of VMA is achievable with the gradation specified in AASHTO MP 8.

The higher VMA are the contributing factor in reducing the permeability regardless of the coarse aggregates used in SMA Mixtures. Research had shown that permeability will not be a problem if the in-place air voids are kept between 6 and 7 % or lower. This appears to be true for a wide range of mixtures regardless of NMAS.

Air Voids (VTM)

Air voids in total mix are treated in both, the Marshall and SMA Design as the single, most important characteristic on which the durability of the asphalt mix depends. Both methods specify a value of 3 to 5 percent for air voids.

Keeping in view the gradation and low asphalt content specified for Marshall Mixes, (especially in our National Specifications) it is very difficult to achieve the specified air voids. The problem of fatigue cracking and rutting mainly erupts from poor mix design, with high air voids and low asphalt binder or vice versa. As mentioned earlier that final mix design should maintain a favorable balance between the gradation and the asphalt content. This balance is rather impossible or difficult to achieve in Marshall Method of Mix Design.

The specified gradation and high asphalt content seems to be in favorable balance in Stone Matrix Asphalt (SMA) which is capable to achieve the properties, as outlined in AASHTO MP 8 and AASHTO PP 41, especially the air voids and VMA.

Research has revealed that asphalt mixes with low air voids are more resistant to fatigue cracking than mixes with high air voids.

RECOMMENDATIONS

Taking the advantage of the research carried out in Europe and America in favor of Stone Matrix Asphalt (SMA), its rut resistant properties and long term durability and also keeping in view the fact that Pakistan would not be able to produce performance grade asphalt binder in near future, it is essentially important to work on the new technology in perspective of the materials available in Pakistan.

The work that needs to be carried out is to review the properties of aggregates from Taxi la, Sargodah and some other sources in Pakistan and to use these materials with penetration grade asphalt binder in producing SMA Mix as per the criteria outlined in AASHTO MP 8 and PP 41. The study should focus on the following as minimum:

- Abrasion Properties of aggregates
- Determination of flat and elongation index
- Soundness of aggregates
- Bulk Specific Gravity and absorption
- Determination of crushed particles
- Voids in coarse aggregates
- Angularity of fine aggregates

- Liquid and Plastic Limits of fine aggregates
- Selection of gradation at different NMAS of aggregate
- Preparation of Briquettes with 50 and 75 blows by Marshall Hammer on each side and 100 gyrations by SGC
- Analysis of density and voids content of Marshall Briquettes including VTM, VMA, VFA and voids in coarse aggregate of the mix
- Determination of $N_{(Desjgn)}$ with Superpave Gyratory Compactor for analysis of air voids
- Determination of aggregates' degradation due to compaction by Marshall and Gyratory method
- To study the behavior of the mix under load by using Asphalt pavement analyzer (APA).
- To study the behavior of the mix under traffic by making trial section on some ongoing projects.

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